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Autonomous and remotely controlled robotic systems of medical evacuation under transition to a digital economy: developments of the Lomonosov Moscow State University and the All-Russian Center of Disaster Medicine "Zaschita"

Abstract. Medical evacuation of severelly ill or injured patients is a complicated and expensive problem. Transportation is performed by highly-qualified medical crew and on special vehicles

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(automobiles, on-land and water transport). Modern digital models enable significantly optimize patient transportation by creating new approaches. Robotization and artificial intelligence within transportation provides opportunity to improve the outcomes with significant reduction of its cost.

Key words — digital economy, artificial intelligence, medical robotics equipment, medical evacuation.

JEL codes: I14, I18.

Usage of Artificial Intelligence (AI) as a new General Purpose Technology (GPT) in the medical area means the necessity to decide serious psychological, juridical and economic problems. In healthcare such decisions are quite clear (for instance, automated appointment to specialists in clinics, digital health records, recording of usage of medications), while in treatment activity it is much more complicated. It is uneasy for a person to accept the fact that medical procedures for him are not only prescribed but also performed by a robot. However this field also develops implementation of artificial intelligence. Let's discuss on the example of medical evacuation of a seriously ill or injured patients.

The modern "injured patient trasnfer model" requires patient delivery to a medical center as quickly as possible with the usage of ultimate methods for "stabilization" of his physical condition. This approach is most effective, but requires special means for providing medical aid at the evacuation stage.

Such means exist, of course. They include a variety of ground-transport ambulances, and cars and ATVs, and specially equipped aircrafts and helicopters that are a part of the air medical service[Goncharov, Garmash, 2012].

How does such evacuation over long distances take place today? A patient is placed on a litter in an ambulance car, then re-placed to an aircraft, then again re-placed to the ambulance car. Each re-placement of the patient is associated with significant risk [Cheung et al., 2014]. A catheter or an endotracheal tube may "fall out". Waiting for loading into an aircraft may be delayed. Long-term therapy should continue during transportation, including the use of automatic syringes, an artificial lung ventilation and hemodialysis. The equipment of the vehicle and the aircraft is different and it needs to be adapted. Using a special aircraft to deliver a patient who has been seriously injured abroad requires time to prepare. Air medical service, medical cross-country vehicles and cars, military medical modules use special transport. A qualified medical team and specialists carrying out transportation (pilots, drivers) are needed. Each individual evacuation costs from 5 to 12 million rubles. Insurance companies do not have such facilities for these purposes; the cost of evacuation should be covered by the patient or sponsors. Solving the money issue also takes time. The patient is therefore in the intensive care unit of a foreign hospital for a long time, the cost of a daily stay in which is high [Delgado et al., 2013].

Another way is possible. The patient is delivered by a scheduled flight. The cost of such delivery is much lower and is equivalent to the cost of tickets for

6 or 9 passengers. In this case, medical stretchers are installed instead of removed aircraft seats (picture 1). The patient is in uncomfortable conditions, it is not possible to provide him full assistance during transportation [Kurnyavka et al., 2017; Gulin et al., 2012].

Picture 1. Replacement of passenger seats to medical stretchers in the cabin of aircraft

Transportation of the patient in cabin of aircraft can be uncomfortable for passengers and in some cases (infection) it is also unsafe. Not only the patient, but also medical equipment need isolation from the external environment. Engine of helicopter usually is turned off during embarkation due to safety reasons (picture 2). That's why temperature inside the helicopter is close to the temperature of the environment. Medical devices and medicines can freeze or overheat under these conditions.

Picture 2. Medical equipment of an "Ansat" helicopter

But there is an even More complicated problem is that medical personnel responsible for transportation are under severe stress. They are forced to make decisions and fulfill assignments in conditions of movement, turbulence, heat or cold. Sometimes they cannot even approach the patient. The doctor is obliged to

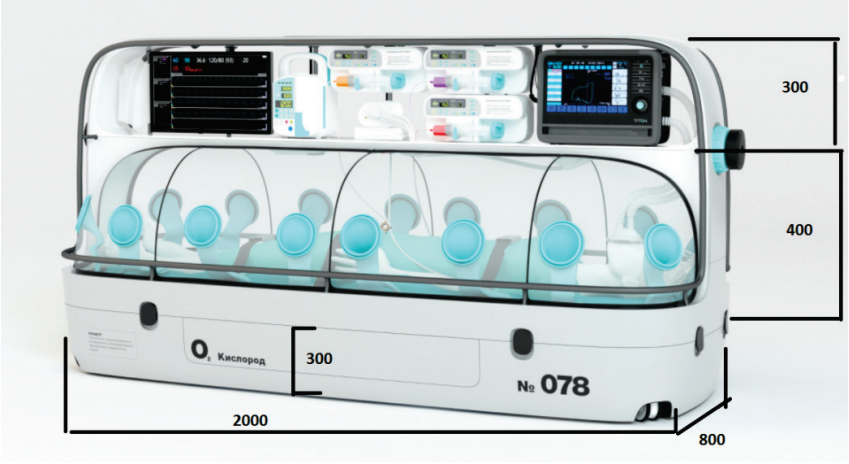
perform the treatment in accordance with giudelines, fix all his manipulations, he has no one to consult with.

There is no particular success in the creation of individual means of evacuation. A "Stretcher" developed by Lufthansa weighs about 200 kg without a patient. It does not isolate patient from external environment [Lutfhansa 2018]. Special means used to transport patients with especially dangerous diseases do not support the temperature regime. A slightest puncture threatens active contamination of the external environment.

It is necessary to take into account the danger of chemical, radioactive, biological threats, the need to work in the most difficult climatic conditions of the Far North or Africa.

Implementation of all requirements in one item is possible in the case of simultaneous use of a robotic medical diagnostic system, life support system, modern materials for building a hull.

A group of specialists from the Lomonosov Moscow State University and the All-Russian Center of Disaster Medicine of the Ministry of Health of the Russian Federation developed the concept of a portable and transportable, isolated medical robotic evacuation device designed for the individual delivery of a seriously ill patient called "Rescue Module" (picture 3).



Picture 3. Portable, isolated robotic medical module for evacuation of an ill or injured patient

The prototype of the medical unit was an upgraded model of the "Angel" (picture 4, 5) complex, which is the only registered medical diagnostic instrument in Russia with a decision support system in emergency situations. It was created in the Lomonosov Moscow State University by a scientific group headed by Academician Viktor A. Sadovnichy and produced at SPO "Splav" in Tula.

Picture 4. Mobile and stationary versions of “Angel”

Picture 5. “Angel” in the intensive care ambulance

Based on the objective diagnostic information received from the patient, 10 urgent conditions are determined and automated treatment using infusion pumps is performed. The system is able to transmit data about the current state of the patient using all types of communication, adjust the treatment depending on the changes in the patient’s condition. Stationary and mobile versions of “Angel” are used in real clinical practice, on intensive care ambulances of All-Russian center of Disaster Medicine “Zaschita”, in hospitals the Tula region. Their informative value, reliability, and usability are approved.

The “rescue module” can be used to provide assistance to the sick and injured persons and pregnant women in emergency situations of both wartime and peacetime. It serves as a mobile individual robotic means of transporting a person with the possibility of providing him with qualified medical assistance in the process of transportation. The “rescue module” is designed to evacuate patients from the point of primary care to a specialized medical institution.

During transportation, the module provides the possibility of an isolated allocation of the patient (in the event of a dangerous infectious disease) and protection against any aggressive environmental conditions (high or low temperature, strong wind, chemical, radioactive, biological pollution).

The "basic" resuscitation complex provides robotic diagnostics and treatment of the following conditions:

— laryngospasm;
— bronchospasm;
— asthmatic status;
— cardiac asthma;
— true drowning;
— pulmonary embolism;
— spontaneous pneumothorax;
— massive pneumonia;
— acute myocardial infarction;
— heart arrhythmia and conduction disorders;
— acute heart failure;
— cardiogenic, hypovolemic, traumatic, burn, infectious-toxic, anaphylactic shock;
— hypothermia;
— acute renal failure;
— chronic renal failure, decompensation;
— chronic liver failure, decompensation;
— ischemic, hemorrhagic stroke, subarachnoid hemorrhage;
— edema of the brain;
— prolonged compression syndrome;
— myasthenic crisis;
— ketoatsidotic, hyperosmolar, laktatsidemic, hypoglycemic coma;
— poisonings;
— Stevens-Jones syndrome (Lyell syndrome);
— Quincke's edema;
— pre-eclampsia, eclampsia;
— epileptic status.

The "rescue module" is fitted with equipment that provides the possibility of routine or robotic implementation of a set of basic functions for qualified medical care.

Diagnostic part of the module is capable of monitoring blood pressure, pulse parameters, electrocardiography, electroencephalography, e-auscultation and mechanical palpation, assessment of external respiration function, oxygen saturation, ultrasound monitoring of the patient, laboratory monitoring of blood and urine.

The medical part includes a system of artificial ventilation of lungs (AVL), the system of automated administration of medication (infusomats and pumps), an automatic system of indirect heart massage and counterpulsation, a defibrillator, a probe for nutrition.

Surgical features enable changing dressings in sterile conditions, carry out the simplest of surgical interventions, for example,hemostasis. Provision is made for dressings, medical instruments, consumables, a stock of medications, a stock of consumables, special ("spinal") shield with devices for fixing the patient on it.

The "rescue module" can additionally contain a functional complex of counterpulsation of limbs and external heart massage and equipment for hemodialysis.

The "rescue module" implements the principle of "Internet of things". It is provided with a remote surveillance system, carried out by a medical professional, both directly next to the module, and remotely, with the possibility of remote transmission of visual and telemetric information.

The "rescue module" has the ability to isolate the patient, medical equipment and medications used and is provided with air preparation systems. The equipment for pumping, filtering incoming and outgoing air, heating, cooling, introducing air, an oxygen generation system, one or several gas cylinders (oxygen, etc.) are provided. There is a system for creating low or high air pressure. Diagnostic devices for monitoring the state of the air environment (temperature, pressure, chemical and radioactive composition) are provided.

The "rescue module" is equipped with an automatic system for collecting human waste products, rinsing and discharged or wound detachable fluid, as well as devices for providing autonomous operation of medical equipment, life support systems.

The "rescue module" has devices for carrying (handles, handgrips) or transporting (wheels, trolley) it. Its overall dimensions and weight allow it to be carried by hand and used on various types of military and civil transport, both land, sea and air (picture 6).

Picture 6. The full-size concept of the module:
the patient block and medical equipment (carbon) block

The “rescue module” should be registered by the Ministry of Health of the Russian Federation as a medical device. It must be certified by aviation manufacturers as a product approved for use in the cabin of a military or civil aircraft or helicopter.

The software of the complex provides protection of personal data in accordance with Federal Law No. 152 “On Personal Data”, as well as the integrity of software components, system settings, stored data and registration information. In the software, logical access control mechanisms are implemented, which are sufficient to meet the requirements of the security policy, logging mechanisms.

Thus, the created concept of the evacuation medical module is compact, can be moved manually or by any means of transport, it is isolated from the external environment, robotized, capable of providing a full range of qualified medical care with a minimum number of personnel in manual, autonomous and remote modes, ready for use without special deployment (picture 7). Responsibility for the decisions made remains with the attending physician who is carrying out the evacuation of the patient. The system and the remote consultant assist in making the decision.

Picture 7. Full-size concept of the module (plexiglas 10mm)

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